Identification of important habitat for the Pilliga Mouse *Pseudomys pilligaensis*

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ABSTRACT

Habitats where rodents breed and congregate provide key refuge and foraging resources and as such may be important for the survival of local populations. The habitat characteristics at spring-time breeding and congregation sites of the Pilliga Mouse *Pseudomys pilligaensis* are analysed here. Data have been gathered from surveys undertaken in 1998-1999 and during a recent survey in 2011. The habitats at the sites (n=11) were found to be shrubby woodland or shrubland dominated by a low shrubby understorey with a projected foliage cover of 20-100%, a groundstorey plant cover of 20-70% and a litter cover of 15-50%. These habitats were found to have floristically diverse understoreys (12-29 species) with a variety of overstorey associations, if present. The results demonstrates that this species occurs in a wider range of vegetation communities than previously reported, though has specific breeding habitat preferences based primarily on understorey and groundstorey conditions. The potential distribution of "important habitat" for *P. pilligaensis* based on these floristic and structural preferences is presented as a predictive map, though it is recognised that the identification of these habitat conditions is best achieved by field examination.

Key words: *Pseudomys*, Pilliga, habitat, shrubby, woodland, important

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Introduction

Pseudomys pilligaensis is a small (10-13 g) murid rodent with a restricted range, currently known only from the Pilliga State Forests, Pilliga East State Conservation Area, Willala Aboriginal Area, Pilliga Nature Reserve and Binnaway Nature Reserve in New South Wales, Australia (NSW Wildlife Atlas, Australian Museum records). The taxonomic status of *P. pilligaensis* is subject to conjecture due to previous work carried out by Ford (2003) though its appearance (rufous pelage, Figure 1), ecological (Paull 2009) and biological aspects of breeding (Prof. B. Breed *pers. comm.*) indicate unique characteristics. Previous studies undertaken during the last significant La Niña weather event (1998-2001) described this species to be "irruptive" and dispersive (Paull 2006; Tokushima and Jarman 2008; Tokushima *et al.* 2008) with a generalist, but seasonally-shifting diet (Jefferys and Fox 2001; Tokushima and Jarman 2010), and with habitat preferences for low shrubs (30-50% projective foliage cover) and for vegetation associations that include recently burnt gullies, Broombush *Melaleuca uncinata* shrubland, acacia-bloodwood *Acacia burrowii - Corymbia trachyphloia* shrubby woodlands and red gum-bloodwood shrubby woodland (Paull 2006; 2009).

Rodents are well documented as having a dynamic population ecology, a strategy which is designed to take advantage of conditions when food is widely available, particularly after rain (Braithwaite and Brady 1993; Southgate and Masters 1996; Madsen and Shine 1999; Letnic *et al.* 2005). Previous studies of *P. pilligaensis* have shown that animals will use the same sites year round, albeit at very different densities, yet will disappear entirely from some sites (Paull 2006; Tokushima *et al*. 2008; Tokushima

Figure 1. A Pilliga Mouse *Pseudomys pilligaensis* trapped during the 2011 survey, showing a rufous tinge to the pelage. Photo: J. McDowell

and Jarman 2008) or appear at sites where they had not been caught previously in the same year (Paull 2006). A similar pattern of low site fidelity has been observed in the closely related *P. novaehollandiae* (Wilson *et al.* 2005) and in *P. fumeus* (Ford *et al.* 2003). As with some other native rodents, autumn densities compared to spring densities can be high in *P. pilligaensis*, with co-habitation, including burrow-sharing, within relatively small areas comprising both sexes and animals of different ages (Paull 2006; Tokushima and Jarman 2008). As well as serving a social function (Ebensperger and Hayes 2008) these high-density autumn sites may be providing an important foraging resource, hypogeal fungi, a food source which this species relies upon in the cooler months (Jefferys and Fox 2001; Tokushima and Jarman 2010) and which may be spatially limited in distribution.

Tokushima *et al.* (2008) suggest that animals disperse to "refuge sites" in the spring, though spring decline in rodents has also been linked with mortality, a decline in fungal forage and dispersal to breeding territories at this time of year (Cockburn 1981; Rodd and Boonstra 1984). This study focuses on the identification of spring-time breeding and congregation sites and the habitats they support, acknowledging that high-density autumn sites are also important for this species' year round use of the forest. Together the habitats required to support these essential behavioural patterns and the resources they provide may be regarded as "important" or "critical" habitat. Identification of the potential distribution of important habitat for *P. pilligaensis* provides key information for the ongoing conservation of this species.

Methods

Data on the habitat of sites where breeding *P. pilligaensis* have been caught was retrieved from two sources; (1) from unpublished data collected from the central area of the Pilliga East State Forest, New South Wales during surveys conducted in 1998-1999 (Paull 2006) and (2) from data collected during a survey for *P. pilligaensis* conducted in October 2011 on the eastern side of the Newell Highway, Pilliga East State Forest (Milledge 2011),. The site locations are depicted in Figure 2. Habitat descriptions of the capture sites (using floristic and structural indices) was undertaken during both survey periods. Structural habitat characteristics of sites were described by identification of the dominant plant species in each stratum together with field estimates of percentage foliage cover at various heights above the ground (<0.5 m, 0.5-2 m, 2-5 m, and overstorey). This was obtained a teach site by using a technique where the cover was recorded where it intersected a vertical line over at least 10 points along a trapping transect. Groundstorey cover included grasses, forbs, prostate plants, mosses, fungi, lichens and cryptograms. Cover of litter and bare ground was also estimated at each point in the same manner. The values for each transect were compiled and averaged. Overall cover preferences for each stratum and groundcover type are expressed as a

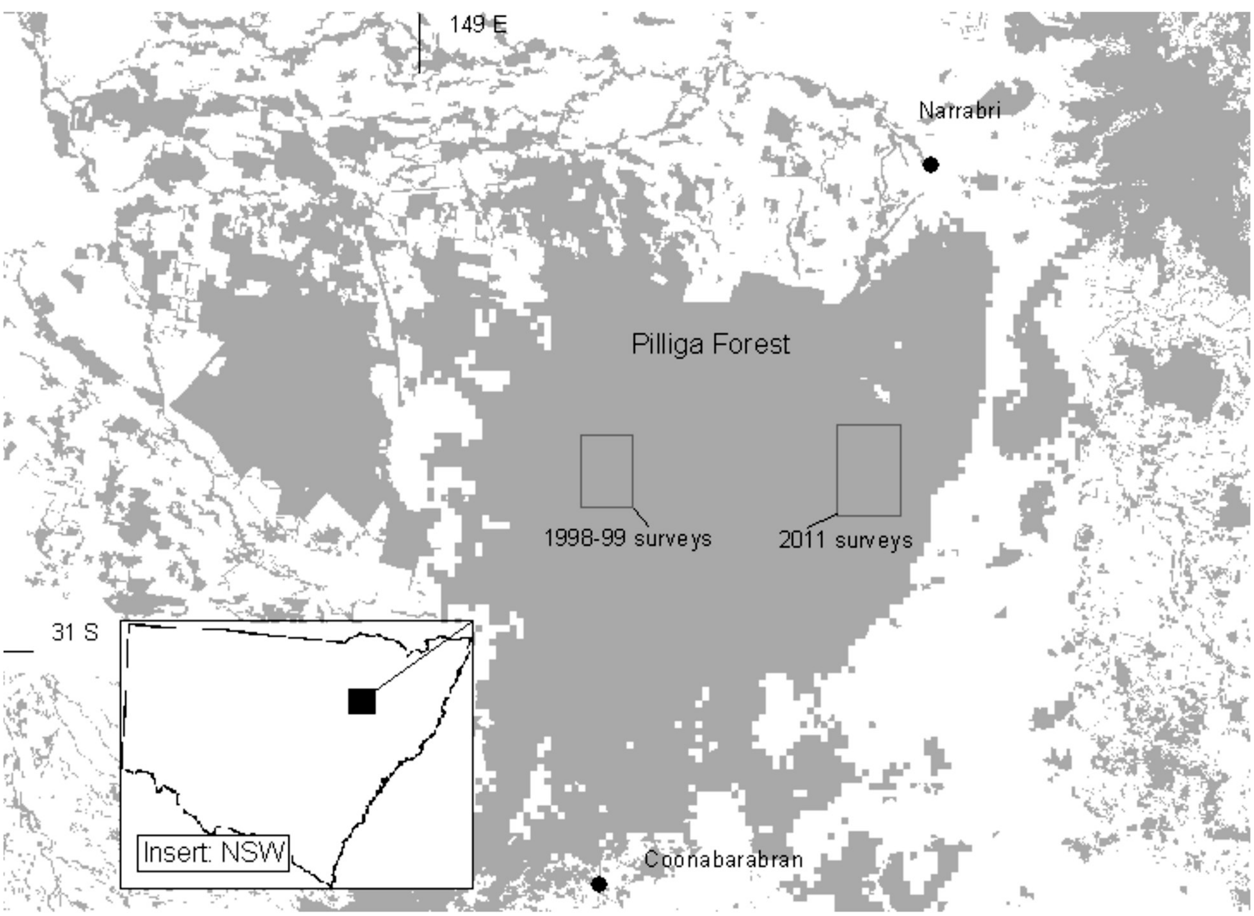

Figure 2. Study Area showing two survey locations

mean with a standard deviation and a range.

Trapping methodologies for the 1998-1999 surveys are described in Paull (2009). Surveys were carried out in October (1998) and November (1999). In the 2011 survey, 10 sites were selected to sample a range of vegetation types in the area. At each site, 50 Elliott A-type traps were set for four nights (200 trap nights site $^{-1}$; 2000 trap nights total). Within each transect, trap stations were placed 10 m apart along two parallel transects (with 25 traps per transect) spaced approximately 50 m apart.

During all survey periods, traps were baited with a peanut butter/oats/vanilla essence or truffle oil mixture and set for four consecutive nights. Traps were checked each morning and re-baited when necessary. Captured animals were sexed and were categorised as being adult (>10 g) or sub-adult (<10 g). Animals were marked with a temporary, water soluble die on the rump. Recaptured animals were distinguished from other individuals by comparing their sex and weight. All animals were released at the point of capture.

Vegetation communities where breeding females have been caught were categorised using Benson *et al.* (2010) and then assigned a corresponding Lindsay Forest Type (Lindsay 1967). For mapping purposes, the distribution and extent of these Lindsay Forest Types was estimated using the GIS layer *ForestTypesFNSW_P.lyr*. Some Lindsay Types could only be assigned as areas "to be determined" because they may contain suitable understorey habitat, but there is uncertainty due to a lack of site data in those types. As a measure of correspondence and accuracy with habitat mapping, the NSW Wildlife Atlas locations for *P. pilligaensis* were added to the mapping product.

Breeding habitat is defined as those areas where female *P. pilligaensis* were captured in breeding condition (pregnant, lactating).

Results

In total, 187 individual *P. pilligaensis* were captured between 1998 and 1999 (Paull 2006), including 35 recaptures. A total of five individuals were caught in the spring of 1998 and 12 captured in the spring of 1999, all being breeding females or juvenile animals. Breeding females were detected at seven sites (Table 1). In 2011, 24 individual *P. pilligaensis* were captured (including eight re-captures) and lactating females were caught at three sites (Sites A, B and C).

For all spring survey periods, sites were occupied by single breeding females, except at site Hc in 1999 which was found to contain a lactating and a pregnant female at the same time. At Site K (2011), eight individuals were captured with some recaptures, but without any animals in breeding condition. This site has been included here as the trapping result indicates a degree of site fidelity and spring-time social group *of P. pilligaensis* (Table 1). Sites B (where seven animals were caught) and K were dominated by adult males and juvenile animals. One lactating female was caught at Site B, though was trapped on a different transect to the other animals.

Floristics

Table 2 shows that throughout the three trapping periods, breeding *P. pilligaensis* were captured in different shrubland and shrubby woodland associations. They were assigned vegetation types as per Benson *et al.* (2010). Shrubland/scrub habitats were dominated by *Melaleuca uncinata* (ID 171) with woodland habitat comprising of a mixture of communities including White Bloodwood /Acacia association (*Corymbia trachyphloia* spp. *amphistomatica*/*Acacia burrowii*) (ID 404); Dirty Gum (Baradine Red Gum *Eucalyptus chloroclada*)-Black Cypress Pine *Callitris endlicheri*-White Bloodwood shrubby woodlands of the Pilliga region (ID 408); Rough-barked Apple *Angophora fibrosa*-red gum-cypress pine woodland on sandy flats mainly in the Pilliga region; (ID 401); and White Bloodwood-Red Ironbark *E. Fibrosa*-cypress pine shrubby sandstone woodlands of the Pilliga region (ID 405). These are depicted in Figures 3-7.

For understorey, the 1998/99 data showed commonly occurring shrub species were *Micromyrtes sessils, Calytrix tetragona, Grevillea floribunda, Westringia cheelii, Eriostemon*

Table 1. Locations of breeding sites for *Pseudomys pilligaensis* (1998-2011)

Site	PM	Dem	Breed	Year	Location (Pilliga East State Forest)	Easting	Northing
2	1	1 af	1	1998	County Line Road	733150	6613200
54	4	1 af; 2 jf; 1 jm	1	1998	County Line Road	711100	6603350
Aa	2	1 af	1	1999	Reilly's Road	715650	6696150
Ca	26	1 af; 1 jm	1	1999	Junction Road	711150	6605700
Gb	12	1 af	1	1999	County Line Road	718250	6605250
Gc	12	2 af	1	1999	County Line Road	718250	6605350
Hc	13	2 af	2	1999	County Line Road	718350	6604400
Site A	1	1 af	1	2011	X-Line Rd	748237	6608034
Site B	7	2 af; 4 am; 1 jf	1	2011	X-Line Rd	752363	6607588
Site C	4	1 af; 3 jf	1	2011	Monument Rd	765271	6609916
Site K	8	4 am; 2 jm; 2 jf	0	2011	Brandons Rd	752135	6613704

PM: Pilliga Mouse individuals caught at site throughout the year (1998/99) and during one spring trapping event (2011); Dem: demographics (a=adult, j=juvenile, f=female, m=male); Breed: Number of breeding females

Table 2. Floristic description of vegetation communities where breeding *P. pilligaensis* have been trapped (1998-2011)

Site	Overstorey dominants	Mid-storey dominants	Understorey dominants	ID*	SP^
1998-1999					
Aa Ca	*Melaleuca uncinata*		*Calytrix tetragona* *Micromyrtus sessilis* *Grevillea floribunda* *Westringia cheelii* *Eriostemon ericifolius* *Damperia lanceolata*	171	18-20
Gb Gc Hc			*Melaleuca uncinata* *Micromyrtus sessilis* *Grevillea floribunda* *Westringia cheelii* *Eriostemon ericifolius* *Damperia lanceolata*	171	15-17
54	*Corymbia trachyphloia,* *Acacia burrowii*	*Dodonaea falcata* *Phebalium glandulosum*	*Hibbertia riparia* *Prostanthera leichardtii* *Gonocarpus elatus* *Actinotus gibbonsii*	404	18
2	*Corymbia trachyphloia,* *Eucalyptus chloroclada*	*Callitris endlicheri*	*Calytrix tetragona,* *Grevillea floribunda* *Brachyloma daphnoides*	408	19
2011					
A	*Corymbia trachyphloia,* *Eucalyptus chloroclada*	*Callitris endlicheri* *Cassinia arcuata* *Conospermum taxifolium*	*Calytrix tetragona,* *Grevillea floribunda* *Brachyloma daphnoides*	408	21
B	*Angophora floribunda* *Eucalyptus chloroclada*		*Boronia glabra,* *Dodonaea peduncularis* *Bossiaea rhombifolia*	401	19
C	*Eucalyptus fibrosa* *Corymbia trachyphloia* *Eucalyptus chlorocada*	*Cassinia arcuata* *Leptospermum parviflorum*	*Brachyloma daphnoides,* *Hibbertia obtusifolia* *Cymbopogon sp.*	405	29
K	*Eucalyptus chloroclada*	*Philotheca salsolifolia*	*Aotus mollis,* *Boronia glabra* *Brachyloma daphnoides*	408	12

*after Benson *et al.* (2010); ^understorey plant species richness

Figure 3. Low woodland dominated by White Bloodwood *Corymbia trachyphloia* and Kurricabah *Acacia burrowii* with a dense lower-storey containing a variety of woody shrubs, where breeding *P. pilligaensis* were captured in 1998 (Benson ID 404). Photo: by D. Paull

Figure 4. Dense post-fire regrowth shrubland, dominated by Broombush *Melaleuca uncinata*, with *Micromyrtus sessilis, Grevillea floribunda, Westringia cheelii, Eriostemon ericifolius* and *Damperia lanceolata* where breeding and over-wintering *P. pilligaensis* were captured in 1999 (Benson ID 171). Photo: D. Paull

Figure 5. Site A where a lactating *Pseudomys pilligaensis* was captured, showing *Corymbia trachyphloia-Eucalyptus chloroclada* dominated woodland with a dense lower-storey dominated by *Calytrix tetragona, Grevillea floribunda* and *Brachyloma daphnoides* (Benson ID 408). Photo: A. McKinley

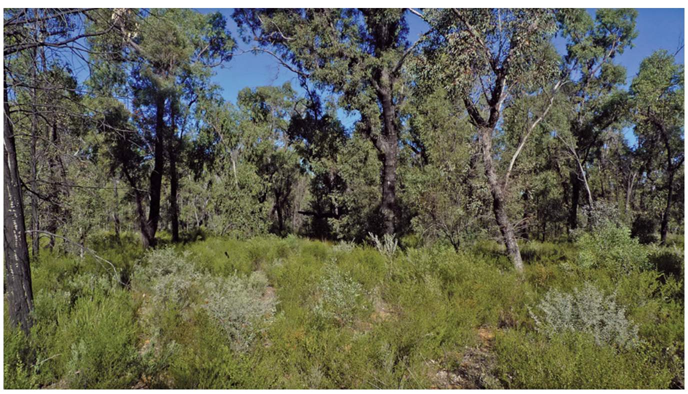

Figure 6. Site B where seven *P. pilligaensis* were captured including a lactating female and sub-adult animals, showing *Angophora floribunda-Eucalyptus chloroclada* dominated woodland with a dense lower-storey dominated by *Boronia glabra, Dodonaea peduncularis* and *Bossiaea rhombifolia* (Benson ID 401). Photo: A. McKinley

Figure 7. Site C where four *P. pilligaensis* were captured including a lactating female and sub-adults, showing *Eucalyptus fibrosa-Corymbia trachyphloia-E. chloroclada* dominated woodland with a dense lower-storey dominated by *Schoenus ericetorum, Hibbertia obtusifolia* and *Cymbopogon* sp. (Benson ID 405). Photo: A. McKinley

ericifolius and *Dampera lanceolata*. In 2011, dominant understorey species were most commonly *Boronia glabra*, *Brachyloma daphnoides*, *C. tetragona* and *G. floribunda.* The latter two were found to be dominant at sites in both 1998/99 and in 2011. Sites where *P. pilligaensis* was recorded were found to have an understorey plant diversity of between 15 to 20 plant species in 1998/99 and 12-29 species in 2011. Sites burnt in the last two years prior to trapping(Gb, Gc, Hb and K) tended to have a lower plant diversity (Table 2).

Vegetation Structure

Table 3 shows the structural characteristics of all sites considered together (n=11). They were found to have a ground combine storey plant cover of 35.9%±14.9 (range = 20-70%) and an understorey shrub cover of 55%±22.7 (range = 20-100%). These sites had a bare ground cover of 30%±19.5 (range = 0-60 %), with a litter cover of 34.1%±10.6 (range = 20-50%). Both overstorey (range 0-60%) and midstorey (0-70%) are not useful habitat predictors due to their high level of variance compared to the mean cover and range values (Table 3). Site data suggests no difference in understorey cover between burnt and unburnt sites, though unburnt sites tend to have less bare ground and a higher level of litter cover.

Mapping the distribution of important habitat

To facilitate mapping of the potential distribution of important habitat for this species, vegetation communities where breeding animals have been caught were placed within the grouped Lindsay Types (Lindsay 1967) of "Apple/ Red Gum", "Broad leaf Ironbark/Bloodwood", "Red Gum/ Broad leaf Ironbark/Bloodwood", "Broombush" and "Acacia/ Bloodwood" (Table 4). Using the digitised Lindsay Type Forests NSW mapping layer, the extent of "potential habitat" (106,839 ha) and habitat "to be determined" (26,603 ha) across the Pilliga East State Forest and Pilliga East State Conservation Area is indicated in Figure 8. The Lindsay Forest Types "Narrow leaf Ironbark-Bloodwood-Red Gum" associations (23,826 ha) and others described as "Heavy Undergrowth" or "Scrub" (2,777 ha) may contain important habitat for this species but have not been investigated.

Discussion

Population density and phenology

In 2011, the average spring-time density of individuals encountered was 3.57±3.05 individuals/site (n=24, range 1-8) while in 1998/99 the average density was found to be lower at 1.88±0.99 individuals/site (n=13, range=1-4). This is similar to overall spring density found by Tokushima *et al.* (2008) who recorded densities of 0-2 individuals .ha $^{-1}$, though one site (2A) recorded 9 individuals/site in October 2000, comprising of mostly males. Both studies show a spring-time social organisation comprising of solitary breeding females and social groups of males and non-reproductive animals at lower densities than in the autumn.

Studies reported hererecorded breeding in October and November which is consistent with the known breeding season of this species, though this time of year is also a time of dispersal (Paull 2006; Tokushima and Jarman 2008).

Table 3. Habitat structure at sites where breeding *P. pilligaensis* were trapped (1998-2011)

site	UH	UC	MH	MC	LH	LC	BG	LL	GC	Burnt
Aa	0	-	2	40	<1	50	10	40	50	No
Ca	0	-	2	70	<1	20	0	30	70	No
Gb	0	-	-	-	<1	70	20	40	40	Yes
Gc	0	-	-	-	<1	100	50	30	20	Yes
Hc	0	-	-	-	<1	70	60	20	20	Yes
2	10	20	2	20	<1	70	30	40	30	No
54	4	60	2	10	<1	60	0	50	50	No
A	15	20	3	20	<1	50	40	30	30	No
B	15	20	0	0	<1	60	40	30	30	No
C	12	15	2	50	0.5	20	30	50	20	No
K	12	15	2	50	0.5	35	50	15	35	Yes
Mean		13.64		23.64		55	30	34.09	35.91	
SD		17.07		23.85		22.66	19.54	10.62	14.9	

Key: UH; Upper vegetation (canopy) height (m); UC: Upper vegetation % foliage cover; MH: Mid-storey vegetation height (m); MC: Mid vegetation % foliage cover; LH: Under-storey Vegetation height (m); LC: Lower Vegetation % foliage cover; BG: Bare ground % cover; LL: Leaf litter % cover; GC: Ground plant % cover.

Table 4. Extent of known breeding habitat associations for *P. pilligaensis* within the Pilliga forests

Overstorey association	Low shrub cover	Ground plant cover	Lindsay Type	Pilliga Extent (ha)*	Source
A. floribunda, red gum	60 %	30%	Rough bark Apple/ Red Gum	30,879.5	Milledge 2011
E. fibrosa, C. trachyphloia	20-50 %	20-30%	Broad leaf Ironbark/ Bloodwood	45,902.6	Milledge 2011
C. trachyphloia, E. chloroclada	30-50 %	30-35%	Red Gum/ Broad leaf Ironbark/ Bloodwood	5,128.6	Milledge 2011 Paull 2006
Melaleuca uncinata,	20-100 %	20-70%	Broombush	23,896.6	Paull 2006
C. trachyphloia, Acacia burrowii	60 %	50%	Acacia/ Bloodwood	1,030.6	Paull 2006
Total				**106 837.9**	

* Lindsay (1967)

Capture of non-reproductive adult females at the same time as reproductive females at different sites confirms that breeding is not entirely synchronous in *P. pilligaensis,* with a breeding season known to extend from October to April (Fox and Briscoe 1980; Paull 2006; Tokushima *et al.* 2008).

Breeding ecology

While the 1998/99 surveys showed that breeding habitat for this species was mostly shrublands/scrubs, the 2011 surveys confirmed that breeding habitat for this species includes woodland vegetation communities with overstories which include *A. floribunda, E. chloroclada* and *E. fibrosa* with a moderate to high understorey cover. Studies undertaken by Tokushima *et al.* (2008) found high numbers of *P. pilligaensis* at four sites, with breeding also recorded at some of these sites, but did not record details of their floristics or structure. They did note in general a "sparse woodland dominated by *Eucalyptus*, *Callitris* and *Angophora* species, with a diverse mid- and understorey of woody shrubs, and a very sparse vegetation, although often much litter, covering the ground".

What may be considered as being a "sparse", or a "moderate", density is unclear, however, the results presented here show that foliage cover at 0.5-1 m in height varied considerably between sites from a relatively low cover (20%) to a high cover (100%). What is consistent in the data collected from 1998/99 and 2011 is the dominance of woody shrubs in the understorey, the high shrub diversity and in some instances the species composition of the understorey. Despite the two study areas being a considerable distance apart (~50 km). Some common understorey dominants in the two study areas were the myrtaceous shrub *Calytnix tetragona*, the proteacid *Grevillea floribunda* and the Epacrid heath *Brachyloma daphnoides*. Tokushima *et al.* (2008) recorded common understorey species of *Boronia, Gahnia, Daviesia*, *Pomax* and *Cassinia* at their study sites in the Pilliga Nature Reserve.

While sites dominated by Broombush *M. uncinata* sustained breeding females and all-year occupancy in 1999, others were trapped without success in both survey periods. This inconsistency may in part be explained by the fire histories of Broombush habitats. Paull (2009) found that only young (1.5- 3 yr old regrowth) and mature (>25 years old) Broombush sites were selected preferentially by *P. pilligaensis*. The age of the Broombush vegetation in the 2011 study was six years since the last wildfire and displayed a growth form with a dense projective foliage cover at 2 metres in height conditions which *P. pilligaensis* was found to significantly avoid.

When compared to species to which it is most closely related, *P. pilligaensis* selects more restricted habitats, perhaps due to a more restricted geographical distribution. *P. delicatulus* has been recorded as breeding in tropical savannahs (Braithwaite and Brady 1993) and coastal sand-dunes (Taylor and Horner 1970). Taylor and Horner (1970) state *P. delicatulus* avoids monsoon forest or woodlands, however other studies have caught this

Figure 8. Distribution of important habitat of *Pseudomys pilligaensis* showing predicted areas (green) and areas to be determined (yellow). NSW Wildlife Atlas records of *P. pilligaensis* are shown in red, and records from 2011 survey are shown in black.

species in tropical *Eucalyptus* woodlands, though breeding is not identified (Kerle and Burgmann 1984; Woinarski *et al.* 2001). *P. novaehollandiae* is known to breed in coastal grasslands, heathlands, regenerating pine plantations and shrubby woodlands (Kemper 1980; 1990; Fox and Fox 1978; 1984; Lock and Wilson 1999), including vegetated coastal dune habitats (Wilson *et al.* 2005). In terms of its habitat selection, *P. pilligaensis* is most like other temperate zone *Pseudomys* species such as *P. novaehollandiae* and *P. fumeus* which also show a preference for habitats with understories dominated by woody shrubs.

Distribution of important habitat

Records of this species obtained from the NSW Wildlife Atlas have been added as a measure of correspondence with the predictive habitat mapping in Figure 8 and despite some outliers to the west, the mapping indicates a reasonably close match between the distribution of records and predicted distribution of important habitat. However it should be noted that not all records represent congregations or breeding sites and some individual records may be represent dispersing animals.

While the extent of possible habitat covers some than 106,800 ha in the Pilliga State Forest and State Conservation Areas at any one time, not all of this area would actually be suitable as important habitat due to local floristic variation and different disturbance and fire histories across the forest. A preliminary field investigation of habitat suitability (Milledge 2011) showed that within a broad area identified as possible habitat only 20% on average was suitable for *P. pilligaensis*. As this species, like other *Pseudomys,* is primarily dependent upon under and ground storey conditions which are regulated by seasonal, stochastic and climatic factors, mapping of important habitat cannot be undertaken accurately without a field assessment of the existing understory conditions using the criteria identified here.

The identification and extent of important habitat for this species is essential for conducting ongoing monitoring of *P. pilligaensis* in order to track longer term population trends, particularly in the context of drought, climate change and coal seam gas production and warrants further investigation in order that predictive modelling can be refined.

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